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Influence of radius of cylinder HTS bulk on guidance force in a maglev vehicle system

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ABSTRACT

Bulk superconductors had great potential for various engineering applications, especially in a high-temperature superconducting (HTS) maglev vehicle system. In such a system, the HTS bulks were always exposed to AC external magnetic field, which was generated by the inhomogeneous surface magnetic field of the NdFeB guideway. In our previous work, it was observed that the guidance force of the YBCO bulk over the NdFeB guideway used in the HTS maglev vehicle system was decayed by the application of the AC external magnetic field. In this paper, we investigated the influence of the radius of the cylinder HTS bulk exposed to an AC magnetic field perturbation on the guidance force in the maglev vehicle system. From the results, it was found that the guidance force was stronger for the bulk with bigger radius and the guidance force decay rates of the bulks were approximately equal despite of the different radius in the maglev vehicle system. Therefore, in order to obtain higher guidance force in the maglev vehicle system, we could use the cylinder HTS bulks with the bigger radius.

1. Introduction

Magnetic levitation based on the interaction between a permanent magnet and a HTS bulk had great potential for various engineering applications [1,2], especially in the high-temperature superconducting (HTS) maglev vehicle system [3]. The stability of the system could be achieved without any complex control owe to the pinning effect of the bulks [4]. So the HTS maglev vehicle could run without complex control at a high speed in the absence of friction. But in practice, the guideway used in the HTS maglev vehicle system was composed of many NdFeB permanent magnets [5], whose surface magnetic field was not always immutable owe to the effect of airgap between the adjacent magnets. When the maglev vehicle was running over this guideway, the bulks onboard would be exposed to time-varying external magnetic field perturbation, which was similar to AC magnetic field. So the guidance force would be varied due to the alternating external magnetic field.

The guidance force, a stable equilibrium force along lateral direction of the guideway, was an important parameter for the HTS maglev vehicle system. If the guidance force was too small, the stability of the whole maglev vehicle system would be affected. In our previous work, we experimentally studied the influence of the AC external magnetic field perturbation on the guidance force of the HTS bulk over the NdFeB guideway. The experimental results showed that the guidance force was decayed by the application of the AC external magnetic field [6]. So we should make efforts to increase the guidance force of the bulk without increasing the guidance force decay rate owe to the AC external magnetic field in the HTS maglev vehicle system.

In this work, we calculated the guidance force based on the critical-state Bean model and investigated the influence of the radius of the cylinder HTS bulk exposed to the AC magnetic field perturbation on the guidance force in the maglev vehicle system.

2. Calculation method

When the cylinder HTS bulk was exposed to AC magnetic field which paralleled to the cylinder axis, the AC magnetic field would start to penetrate into the bulk from the surface. And the magnetic flux movements in the penetration areas would result in AC loss. However, the thermal conduction ability of the bulk was bad. So the temperature of the bulk would rise, and the critical current density would be decreased. Based on the theory mentioned above and the critical-state Bean model, an analytic model was given, as shown in Refs. [7,8]. So the critical current density decay of the bulk exposed to AC magnetic field could be evaluated.

According to the critical-state Bean model, a numerical method was developed for evaluating the guidance force of the bulk over

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the NdFeB guideway, in which the current density distribution of the YBCO bulk was calculated by the method proposed by Prigozhin [9]. The action between the current density of the HTS bulk and the NdFeB guideway was shown in Fig. 1.

And the guidance force F_{gui} of the bulk could be given by the following formula:

$$F_{gui} = \int_s J \times B ds$$

where J was the current density, B was the guideway magnetic flux density computed by the FEM method, and S denoted the cross-section of the HTS bulk. In these calculations, the HTS bulk and the NdFeB guideway were treated as infinitely long and uniform along the guideway direction so as to simplify the calculation.

3. Results and discussion

Based on the calculation method mentioned above, we calculated the guidance force of the bulk whose radius was set to different values to investigate the influence of the radius on the guidance force in the maglev vehicle system. In the calculation, we employed the following procedure. Firstly, the YBCO bulk in the normal state was placed above the NdFeB guideway at a certain height. Secondly let the bulk transit to the superconducting state in the presence of magnetic field generated by the guideway. We called this process field-cooling (FC). The gap between the bottom of the bulk and the surface of the guideway was field-cooling height (FCH). Thirdly, AC external magnetic field was applied to the bulk and the directions were paralleled to the c axis of the cylindrical bulk. Finally, moved the bulk to a certain lateral displacement along the lateral direction and measured the guidance force. In this step, the gap between the bottom of the bulk and the surface of the guideway was called work height (WH), and the distance between the centre of the bulk and the one of the guideway surface was called lateral displacement (LD). The calculation parameters were as follows: the thickness H of the YBCO cylindrical bulk was set to 15 mm, the frequency f and the amplitude B_{ac} of the AC magnetic field were 120 Hz and 0.046 T, the field-cooling height (FCH), lateral displacement (LD) and the work height (WH) were set to 10 mm, 20 mm and 10 mm, respectively. The radius R of the YBCO cylindrical bulk were set to 15 mm,16 mm, 17 mm, 18 mm, 19 mm and 20 mm, respectively.

When the AC magnetic field was not applied, the value of the guidance force was called initial value. With the application of the AC magnetic field, the guidance force decayed and would relax to achieve stability, and the value of the guidance force at this moment was called stable value, as shown in Ref. [6]. The guidance force decay which was obtained by subtracting the stable valve from the initial value. The ratio of the guidance force decay to the initial value was defined as the guidance force decay rate. We calculated the guidance force of the bulk cylinder which had different radius, as shown in Fig. 2.

Fig. 2 showed the guidance force of the cylinder HTS bulk exposed to AC external magnetic field with the different radius. The curve of the initial value was always on the top of the curve of the stable value. It meant that the guidance force of the bulk was decayed owe to the application of the AC external magnetic field and the stable value was always smaller than the initial value. Furthermore, with the radius of the bulk increased, the guidance force also increased. Therefore, we could use the cylinder bulk with bigger radius to obtain higher guidance force in the maglev vehicle system.

In order to further investigate the influence of the radius on the guidance force decay of the cylinder HTS bulk exposed to AC magnetic field perturbation in the maglev vehicle system, we calculated the guidance force decay rates of the bulk cylinder with the different radius, and the results were shown in Fig. 3. From the results, we could conclude that the guidance force decay rates of the cylinder bulks were approximately equal despite of the different radius. In other words, the guidance force decay rates of

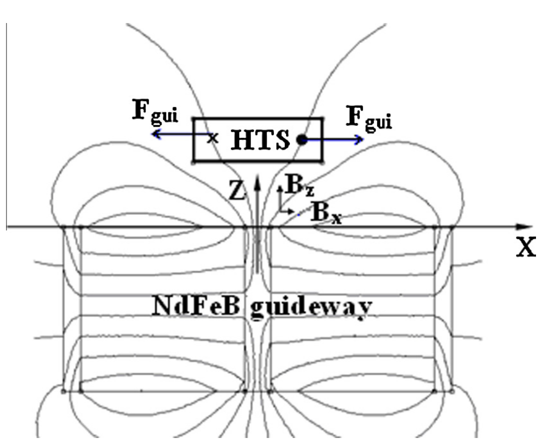

Fig. 1. Schematic drawing of the action between the current density and the guideway.

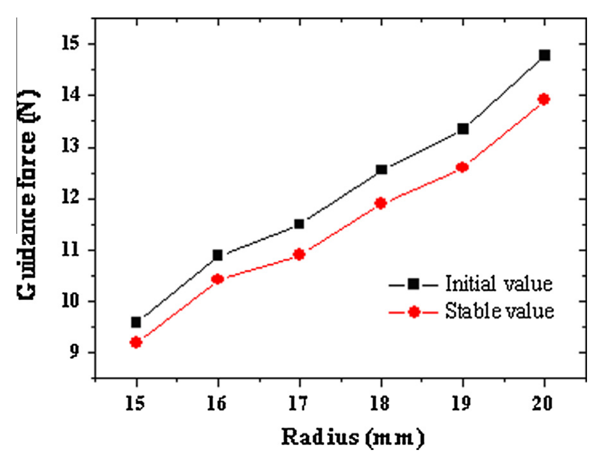

Fig. 2. The guidance force of the bulk exposed to AC external magnetic field with the different radius.

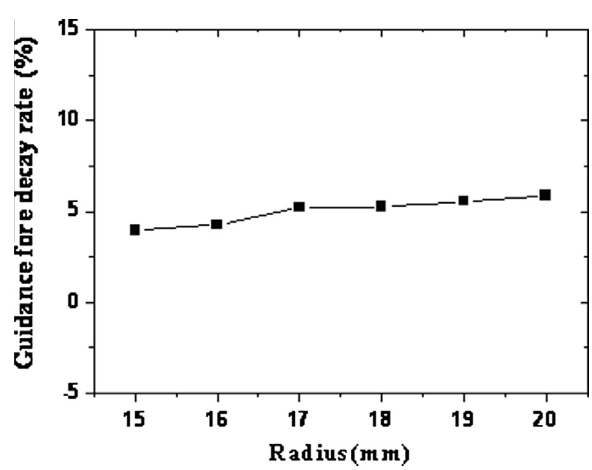

Fig. 3. The guidance force decay rate of the bulk exposed to AC external magnetic field with the different radius.

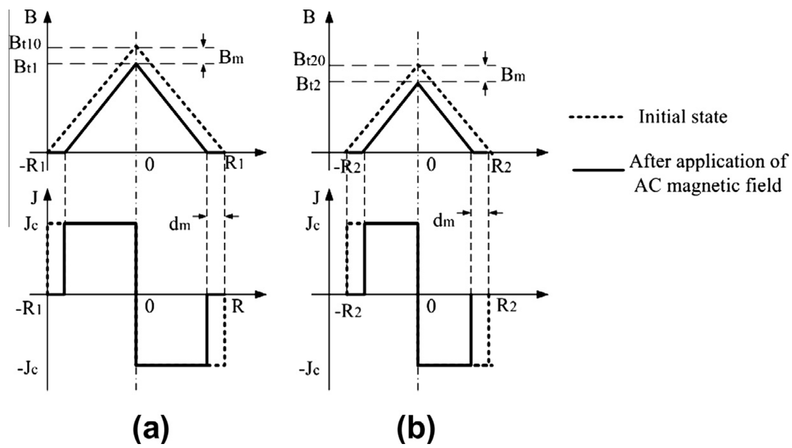

Fig. 4. Distributions of the trapped magnetic field B and current density J in the bulk exposed to AC magnetic field: (a) the radius of bulk was R_1; and (b) the radius of bulk was R_2. ($R_1 > R_2$).

the cylinder HTS bulks exposed to AC magnetic field perturbation were almost independent of the radius.

According to the Bean critical-state model [10], for an infinitely long superconducting cylinder of radius R subjected to external AC magnetic field of amplitude B_{ac} paralleled to the cylinder axis, the distributions of the trapped magnetic field B and current density J were shown in Fig. 4.

J_c was the critical current density of the bulk. In the initial state, the distributions of the trapped magnetic field and the shielding current in the cylindrical bulk were shown by dashed line in Fig. 4.

The YBCO bulk was cooled over the NdFeB guideway, so the bigger the radius of the bulk was, the stronger the trapped magnetic field of the bulk was. Therefore, the trapped magnetic field B_{t10} of the bulk whose radius was bigger was stronger than the trapped magnetic field B_{t20} of the one whose radius was smaller, as shown in Fig. 4. However, the guidance force was dependent on the trapped flux [11]. So the cylinder bulk with the bigger radius provided larger guidance force, as shown in Fig. 2.

When the bulk was exposed to AC magnetic field, the AC filed would start to penetrate into the cylinder from the surface, and the penetration depth of the AC field d_m was given by the following equation [7].

$$d_m = B_{ac}/\mu_0 J_c$$

where μ_0 was the magnetic permeability in vacuum. Therefore, no matter whether the radius of the cylinder HTS bulk was equal or not, the trapped penetration depths d_m were always equal owe to the same amplitude B_{ac} of the AC field, as shown in Fig. 4. Furthermore, the amplitude B_{ac} of the AC field applied to the bulks was small in this paper. So the trapped penetration depths d_m were also small, and much smaller than the radius of the bulks.

When the AC field was decreased gradually to zero, the magnetic field and the shielding currents in the penetration area would become zero, so the guidance force would be decreased. The distributions of the trapped magnetic field and the shielding current in the bulk were shown by real line in Fig. 4.

The peak values of the trapped magnetic field of the bulks whose radius was R_1 and R_2 were denoted by B_{t1} and B_{t2} in this state, respectively. From Fig. 4, it was conclude that the tapped magnetic field was decay owe to the application of the AC magnetic field. And the decay rate of the bulk whose radius was R_1 was smaller than the one of the bulk whose radius was R_2. So the guidance force decay rate of the bulk whose radius was bigger was also smaller. But in practice, the amplitude B_{ac} was small, so the trapped penetration depths d_m were also small, and much smaller than the radius of the bulks. Furthermore, the radius of the cylinder HTS bulk were set to 15 mm, 16 mm, 17 mm, 18 mm, 19 mm and 20 mm, respectively. There was a small difference among the radius. So the guidance force decay rates of the cylinder bulks were approximately equal, as shown in Fig. 3.

Therefore, in the high-temperature superconducting maglev vehicle system, we could use the cylinder HTS bulks with the bigger radius. This was because that the cylinder bulk with the bigger radius provided larger guidance force, while guidance force decay rate compared with the one with the smaller radius was approximately equal.

4. Conclusion

In the high-temperature superconducting maglev vehicle system, the guidance force was one of the important parameters, and attenuated with the application of the AC external magnetic perturbation caused by the inhomogeneity of surface magnetic field of the NdFeB guideway. Based on the critical-state Bean model and the calculation method in our previous work, we investigated the influence of the radius on the guidance force decay of the cylinder HTS bulk exposed to AC magnetic field perturbation in the maglev vehicle system. From the calculated results, it was concluded that the guidance force was stronger for the cylinder bulk with bigger radius and the guidance force decay rates of the cylinder bulks exposed to AC magnetic field perturbation were almost independent of the radius. Therefore, in order to obtain the higher guidance force in the maglev vehicle system, we could use the cylinder bulks with the bigger radius.

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